Prospects for and value of long-time series data, including using global reanalysis data sets, in the development of global climate derivatives – and other uses.

Roger Stone, Peter Best, Olena Sosenko

MANAGING CLIMATE VARIABILITY
R & D PROGRAM

USQ AUSTRALIA

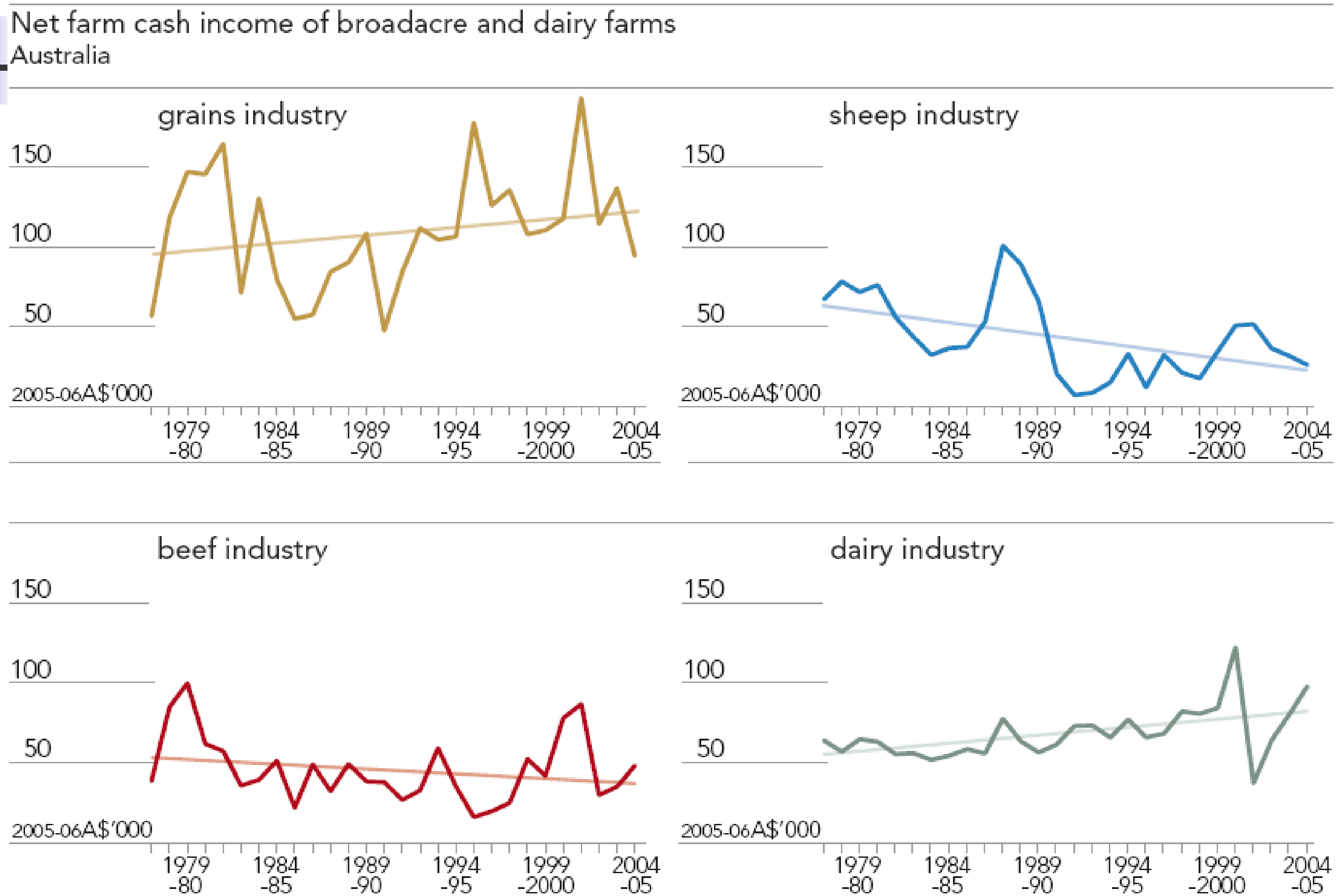
Cindual Pty Ltd

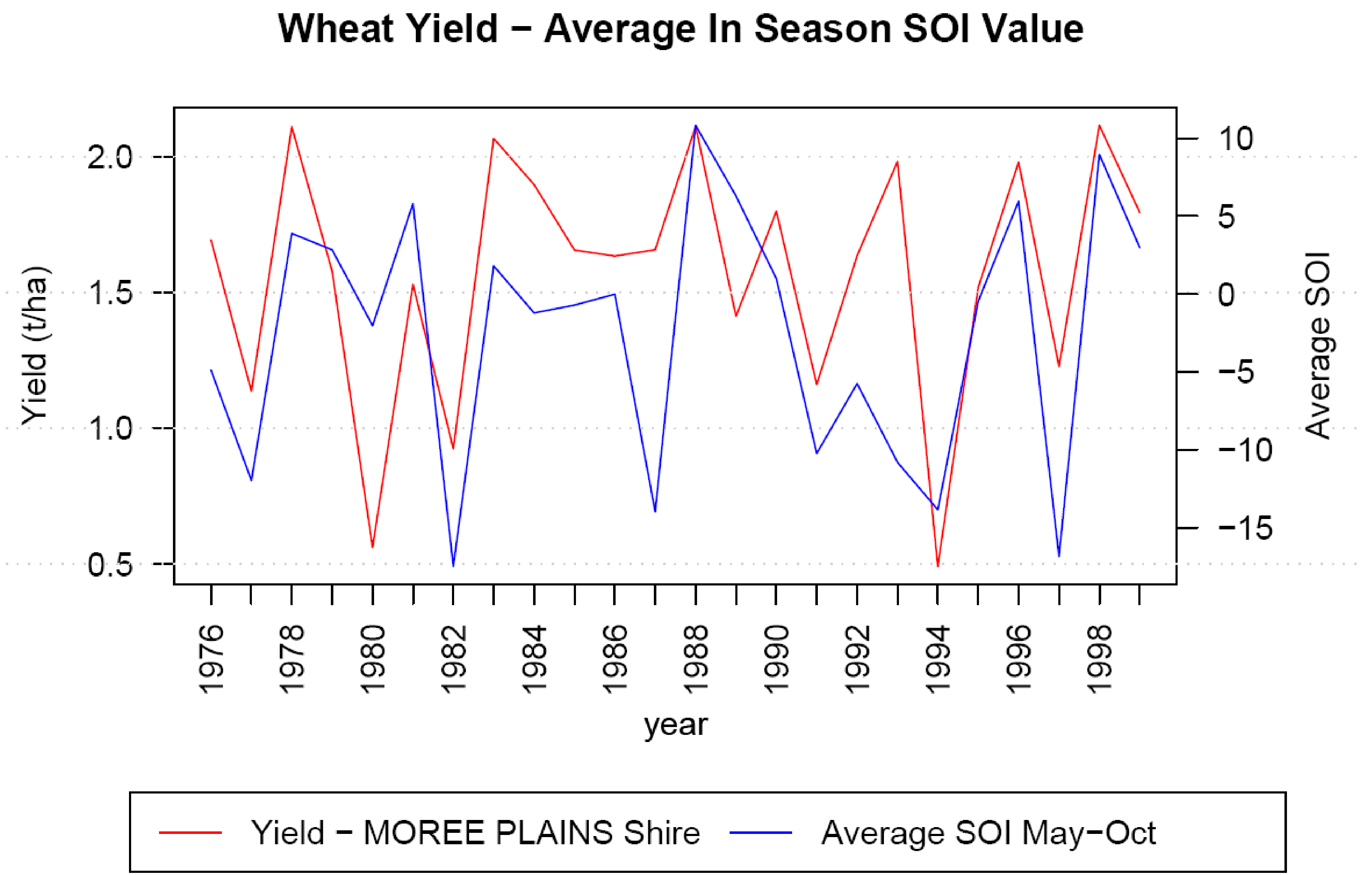
primacy
insurance for all seasons

- Stern and Dawkins (2004) note that, although ‘there are pockets of Australia’ in which seasonal forecasts for rainfall have only marginal skill, beneficial risk management using seasonal forecasts <u>together with a partial hedge with weather derivatives</u> requires forecasts only marginally better than climatology.

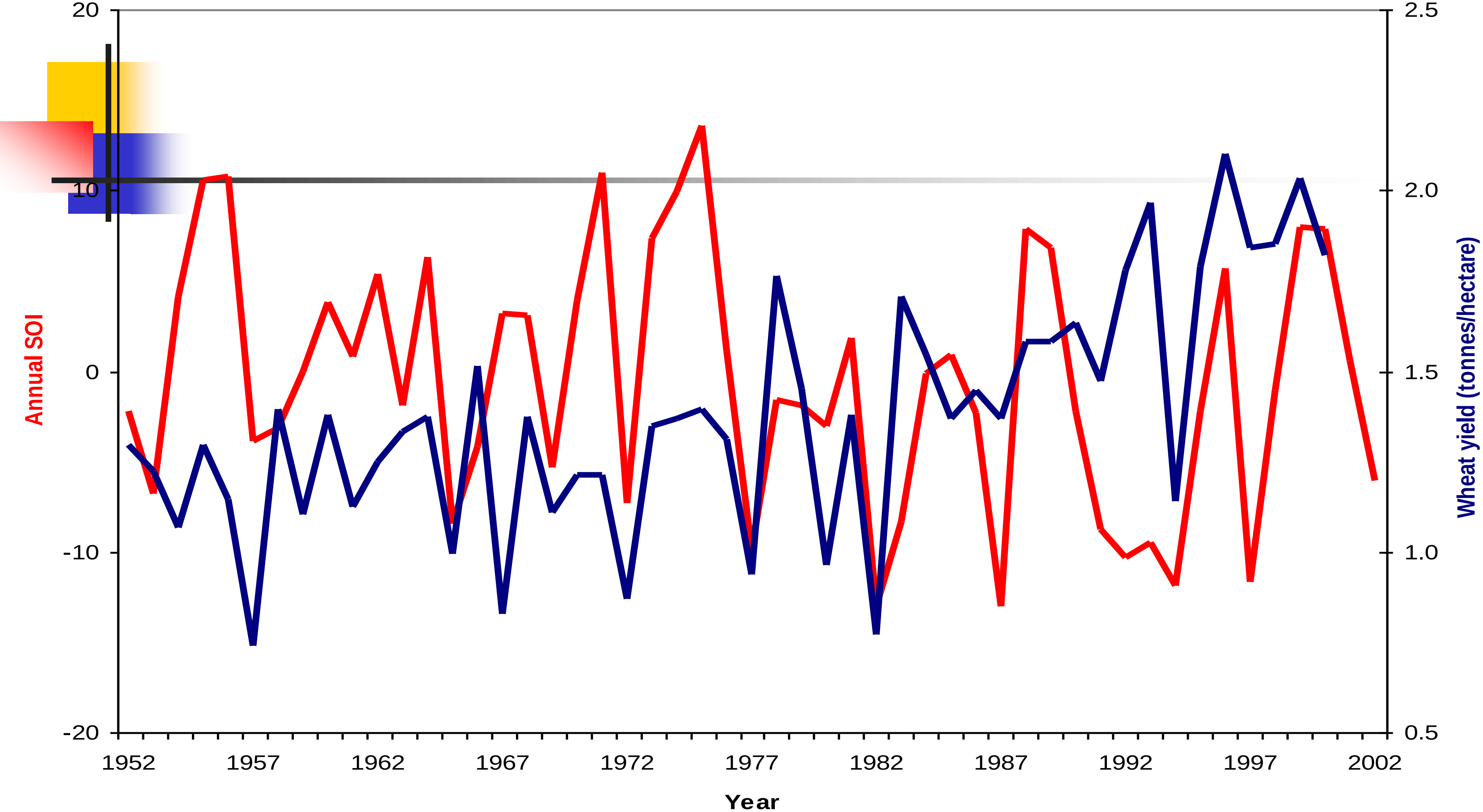
- Weather risk tools and the use of currency swaps (to manage price risk) should produce better hedging against aspects such as drought than waiting to assess the production volume at harvest and selling into an end-of-season pool market.

Volatility of ag production





Assessment of agricultural yield and a major climate driver: however, it is more than SOI alone (and reanalysis data sets of SOI also valuable) – need for new indices/combined indices…



Not the same for all production regions - relationship between annual variation in the SOI and annual *Australian* wheat yield (N Nicholls).

Probability of exceeding Median Rainfall

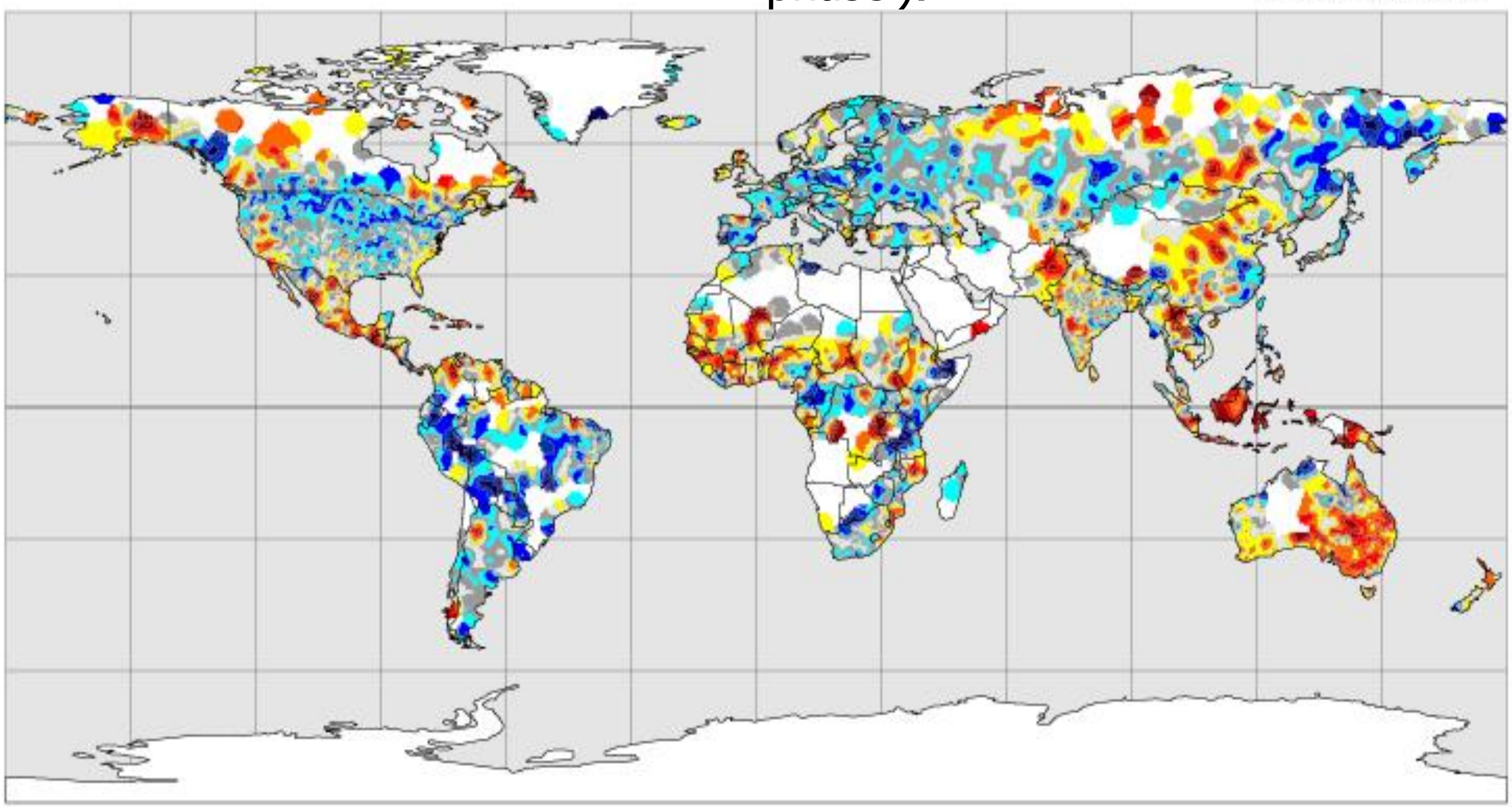
for July / September
based on consistently negative phase
during May / June

Queensland Government
Department of Primary Industries

(Stone *et al.,* 1996)

Global indices - spreading risk globally (rainfall probability values associated with 'consistently negative SOI phase').

	90 - 100%
	80 - 90%
	70 - 80%
	60 - 70%
	50 - 60%
	40 - 50%
	30 - 40%
	20 - 30%
	10 - 20%
	0 - 10%
	No nearby stations or seasonally dry



Rationale for use of indices:

•Global and hemispheric climate indicators have proved useful in many countries for characterising intra- and inter-annual variability in climate processes, agricultural output and biomass production.

•Global Indices also form the basis of successful seasonal climate and production prediction systems for the probability distributions of allied parameters such as rainfall or crop yield.

•Climate risk management via derivative, insurance or bond instruments has only recently incorporated non-local climate parameters such as "teleconnection" indices in payoff functions and overall design.

- A feasibility study of using an index such as the Southern Oscillation Index in weather derivatives for the Australian wheat industry has *suggested several such climate-anomaly* indicators as suitable vehicles for managing risks of various types, including the hedging of likely errors in seasonal climate forecasting.
- Potential benefits should accrue if the co-joining of weather/climate risk management and seasonal forecasting is encouraged across many weather-sensitive industries (e.g. agriculture, mining, energy and tourism), if longer-term perspectives of risk across many seasons are adopted and if support is given to suitable trading mechanisms and industry extension programmes..

Weather risk management (WRM) involves:

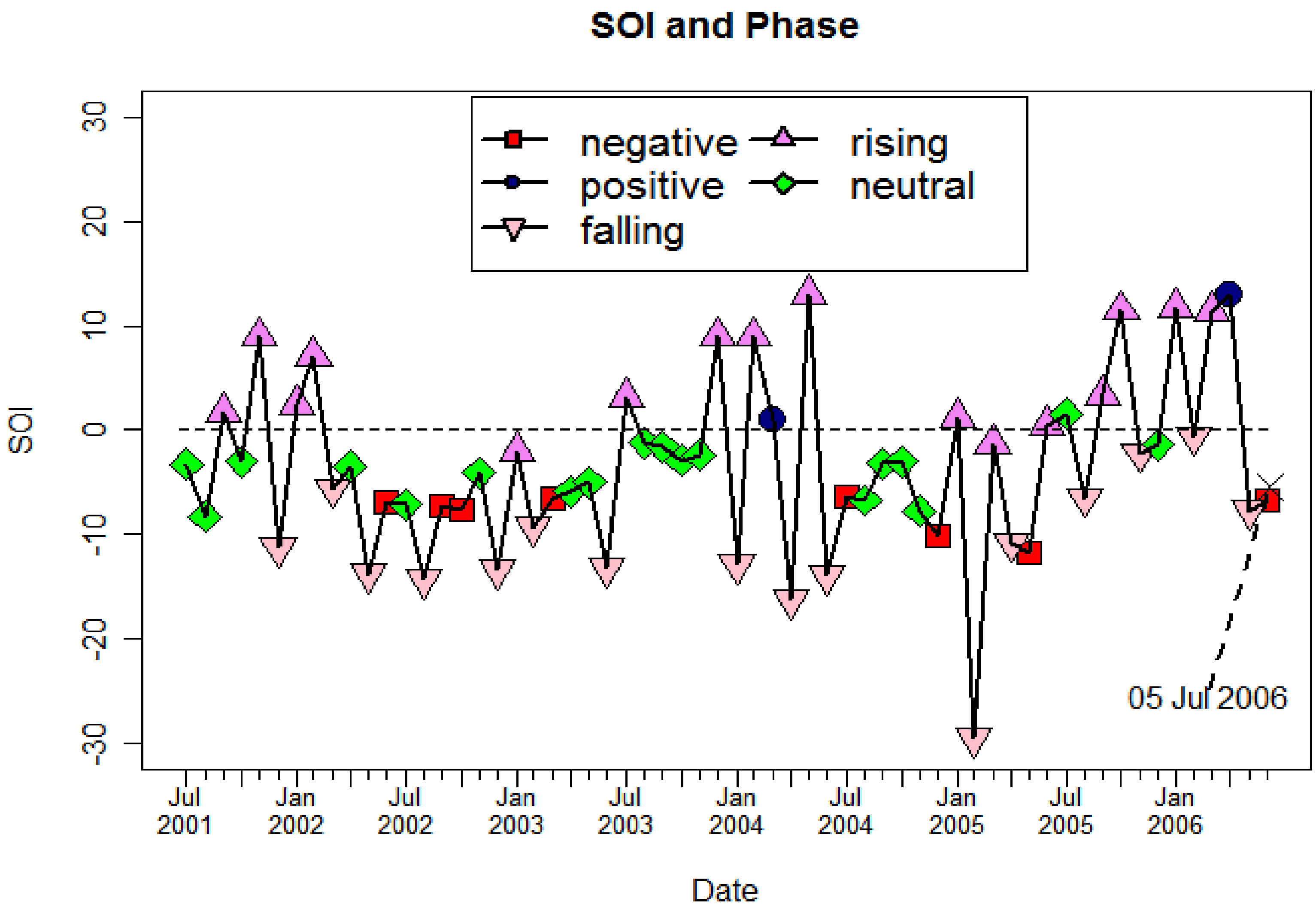
•developing decision and hedging strategies for various time horizons.

•accommodating for the "predictable" component via various types of business-weather models and cycles, be they deterministic, heuristic and/or statistical.

•determining how much weather noise exists (WRM aims to minimise any impacts); and

•estimating distributional characteristics or variability of weather noise over time/space, simulating time series of weather noise at key locations and ensuring the appropriate memory, extremes and transition properties of resultant models.

More practical climate forecast and anomaly indicators – use of the Southern Oscillation Index remains popular and has 'global' impact



(Stone *et al.*, Nature, November 1996)

Example of different CAIs applicable to various regions

- <u>Global indicator v site-specific index</u>. "Rather than dealing with a site-specific index such as Sydney seasonal rainfall, index, CAI -based - instruments deal with global parameters (e.g. SOI, NAOI) and so avoid most problems of missing data, measurement error and intra-regional differences.
- More importantly, they should be more transparent and tradable, since other markets and countries can map their own risks onto an underlying CAI".

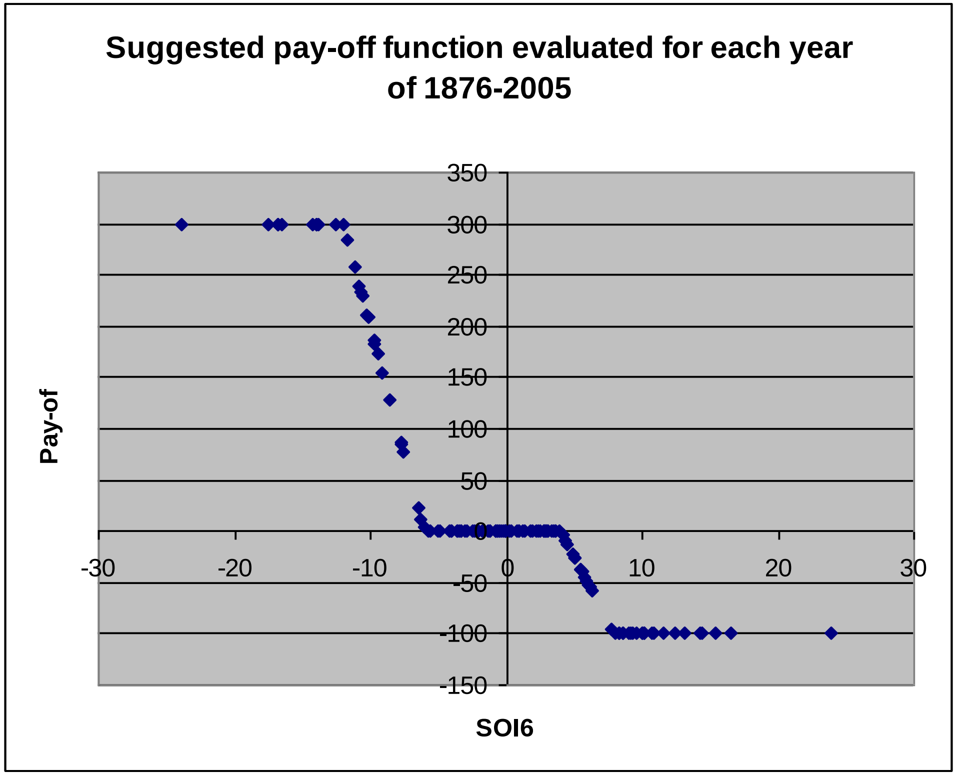
The need for long-term indices..

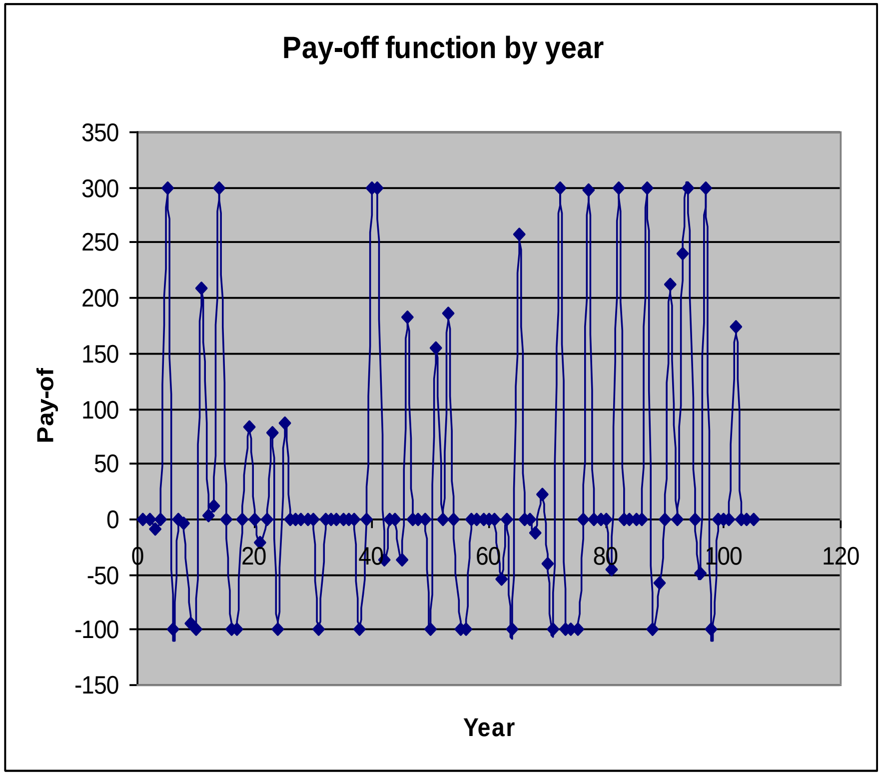
- “Weather derivatives depend strongly on having a long and relevant historical record of weather parameters at a number of key locations within a given country.
- Climate Anomaly Indicators (CAIs) should be constructed for at least 100 years of information (by judicious choice of representative sites) and are potentially applicable to production or weather variables in many countries.
- CAIs should handle the effects of inter-decadal variability and climate change better than products based on relatively short-term meteorological records,
- There is always a need for long-term indices…re-analysis systems may solve that problem…..

How can Climate Anomaly Indices products be priced?

- Burn analysis (using historical information to evaluate what the insurance risks or derivative payoff functions would be if future weather was very similar to that in the past - assumes similar state in the future to the past)
- Index distributional analysis (estimation of the statistical distributions of the relevant weather index followed by re-sampling or simulation schemes).
- This approach overcomes problems associated with missing data, short data series and choice of data period when using "burn" methods, but requires longer-term proxy records of CAIs and an appreciation of climate trends - may this be avoided with use of good re-analysis data sets?

Example of collar product based on a global index – in this case the SOI



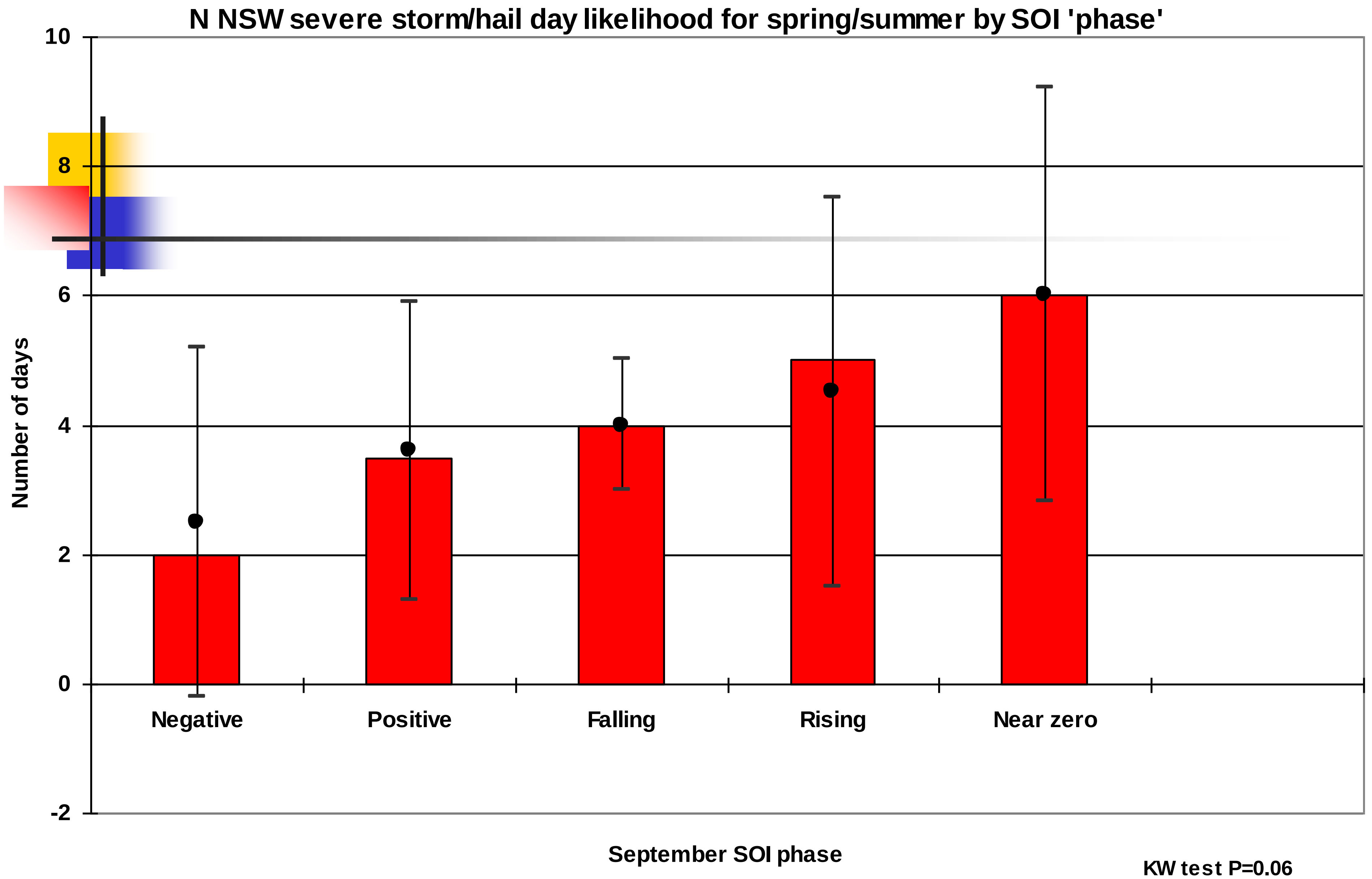


SOI collar derivative: pay-off function, premium and net profit for various climate epochs

Epoch	Mean SOI6	SD (SOI6)	Mean F	SD (F)	Premium	Farmer net (Payoffs-premium)
All(1901-2005)	-0.65	8.01	20.5	115	43.5	-23.0
'Warm' 1 (1910-47)	-0.04	8.08	22.7	105	43.8	-21.0
'Cold' (1948-77)	1.34	8.36	10.4	115	33.5	-23.0
'Warm' 2 (1978-2005)	-2.12	7.68	52.7	128	78.3	-25.0
1876-1909	-0.05	8.56	22.8	122	47.3	-24.5

Example of different potential indices - CAIs - applicable to various regions

- SOI – cross-Pacific ocean-atmosphere phenomenon, periodicity 2-7 years - ~120 years data available but may still have problems …are the following also useful?
- Nino 3.4 and IODI – area average sea-surface temperature in Pacific/Indian Oceans – 50 years' index data (so far)…
- NAOI – non-Pacific Northern Hemisphere pressure patterns, periodicity 2-5 years…50 year's index data (so far)
- AAOI – Antarctic Oscillation Index –
- SAMI – Southern Annular Mode Index ..
- LSTR – latitude of the sub-tropical ridge.
- Hailstorm indices...



N NSW severe storm/hail day likelihood for spring/summer by SOI 'phase'
10
8
6
4
2
0
-2
Number of days
Negative
Positive
Falling
Rising
Near zero
September SOI phase
KW test P=0.06

The NCEP-NCAR daily re-analysis with a spatial horizontal resolution of 2.5 x 2.5 lat-lon are used to determine the forcings for severe TS/hailstorms in the past..

Relevant atmospheric quantities:

Lapse rate: T850-T500

Precip water in the column 850-500hpa.

RH: ratio between environmental vapour pressure and saturated vapour pressure, averaged between 850/500hpa.

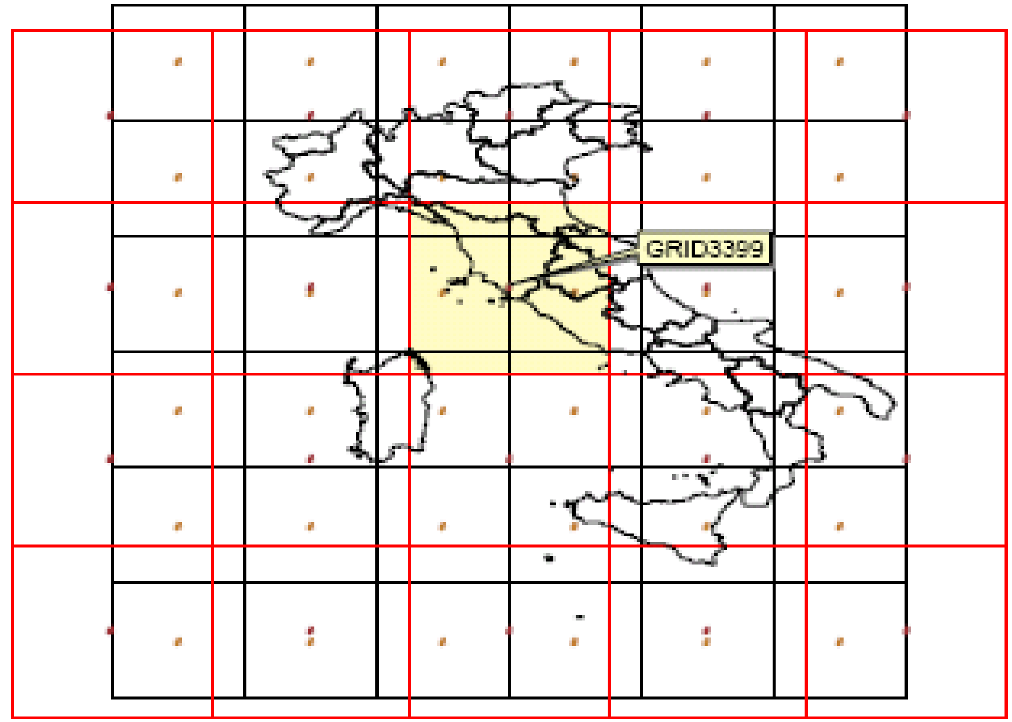


Fig. 1. Reanalysis Grids (2.5°×2.5° Lat-Lon, black) and CCCma Scenario Grids (3.75°×3.75° Lat-Lon, red) over Italian area with indication of the grid considered to present results of analysis.

"In almost all countries - No homogenous time series of hailstorms are available"

Piani, F., Crisci, A., De Chiara, G., Maracchi, G., and Meneguzzo, F (2005) 'Recent trends and climatic prespectives of hailstorms frequency and intensity in Tuscany and Central Italy' *Natural Hazards and Earth Systems Sciences*, **5**, 217-224.

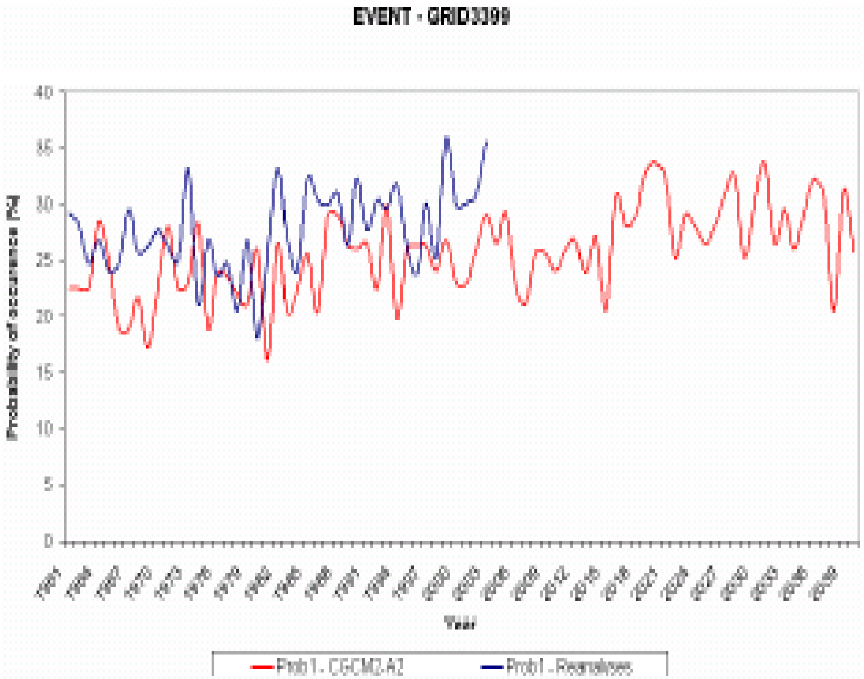


Fig. 2. Annual trend of hailstorm frequency.

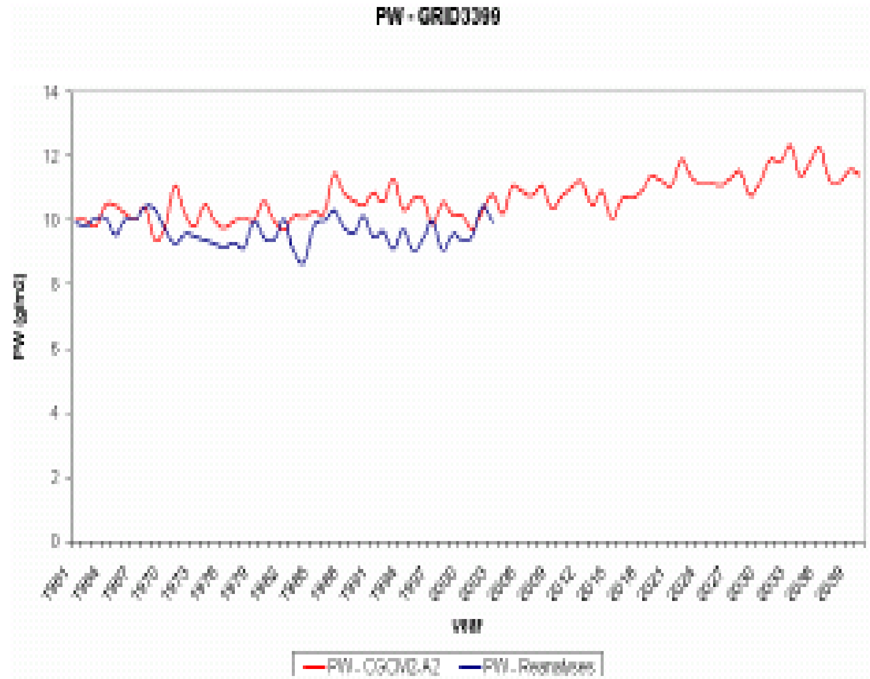


Fig. 4. Annual values of Precipitable Water.

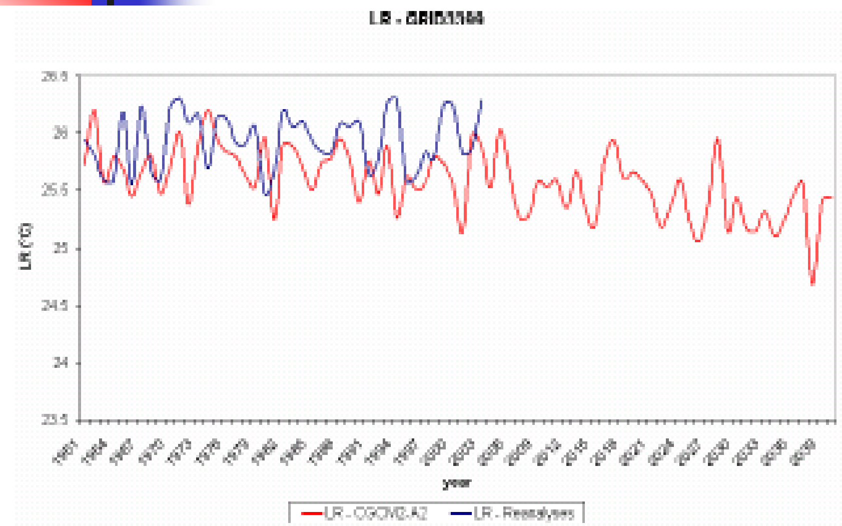


Fig. 3. Annual values of Lapse Rate.

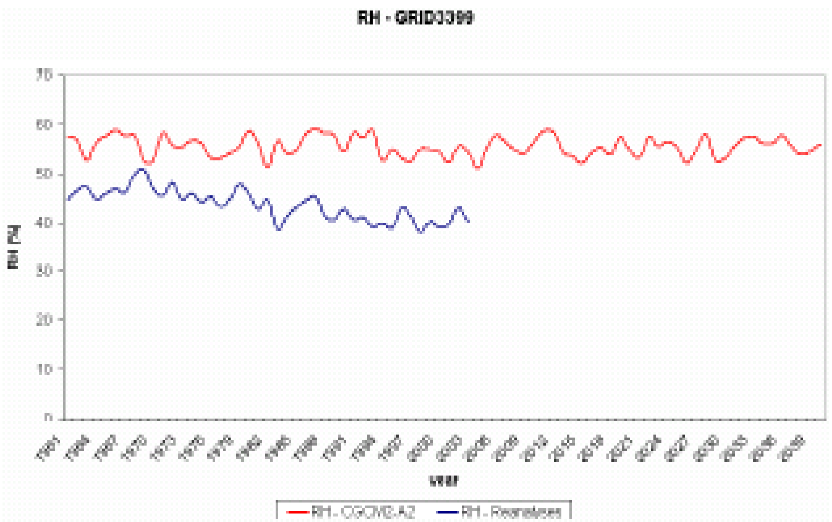


Fig. 5. Annual values of Relative Humidity.

Summary

- *Global indices* (eg SOI) hold promise for risk management at varying spatial and temporal scales.
- There is value in applying CAI (eg 'climate derivatives') as an adjunct to climate forecasting systems in order to better manage risk.
- Even in eastern Australia, relationships between SOI (May to Oct) and wheat yield are not entirely conclusive.
- Therefore, need to access suitable data sources of other key indices (NAO, SAM, Nino 3.4) in order to price these systems..(also enhances the value of reanalysis approaches).
- Additional value for such systems as severe thunderstorm/hail risk.
- The pay-offs could be substantial..


Flávio Gassen

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Thanks to Primacy Underwriting Agency and QBE Insurance for contributing an information about insurer and farmer point of view and also to the many farmers and agribusiness companies in Australia who participated in interviews and contributed to this research.

Thanks Peter Best, Olena Sosenko for input and to Rob Allan and Gil Compo for 'showing me the light'…

How can Climate Anomaly Indices products be priced?

- Burn analysis - but using the output of stochastic weather generators based on seasonal forecasts and historical information. This may be an easy way of melding forecasts and their updates as the season progresses and revaluation of contracts is required;
- Stochastic differential equation models (e.g. temperature or 'daily SOI' satisfying a "mean-reverting Brownian motion with log-normal jumps and time-varying volatility", The incomplete nature of the market then requires use of either "risk-neutral" martingale approaches, "equilibrium pricing models" to incorporate the market price of risk or models that implicitedly include a risk premium for the non-traded asset ;
- Modified Black-Scholes techniques, e.g. accumulated weather indices have almost-normal distributions and conventional pricing techniques may be appropriate.

approach, a complex system is presented as a set of connected nodes. The collective behavior of all the nodes and links (the topology of the network) describes the dynamics of the system and offers new ways to investigate its properties. The indices represent the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO), the El Niño/Southern Oscillation (ENSO), and the North Pacific Oscillation (NPO) [*Barnston and Livezey*, 1987; *Hurell*, 1995; *Mantua et al.*, 1997; *Trenberth and Hurrell*, 1994].

These indices represent regional but dominant modes of climate variability, with time scales ranging from months to decades. NAO and NPO are the leading modes of surface pressure variability in northern Atlantic and Pacific Oceans, the PDO is the leading mode of SST variability in the northern Pacific and ENSO is a major signal in the tropics. Together these four modes capture the essence of climate variability in the northern hemisphere. Each of these modes involves different mechanisms over different geographical regions. Thus, we treat them as nonlinear sub-systems of the grand climate system exhibiting complex dynamics. Indeed, some of their dynamics have been

Utility of CAI risk management products for wheat industry

Q1. Will CAI-derivatives be more useful than other types of weather risk products?

Q2. What benefits may accrue to wheat-industry stakeholders using SOI derivatives?

Q3. How can such products be constructed, priced, evaluated and promoted?

Q4. What synergies for users of both seasonal forecasting and climate risk products?

Q5. Are there additional indices (through reanalysis systems) that could be of use in this application?

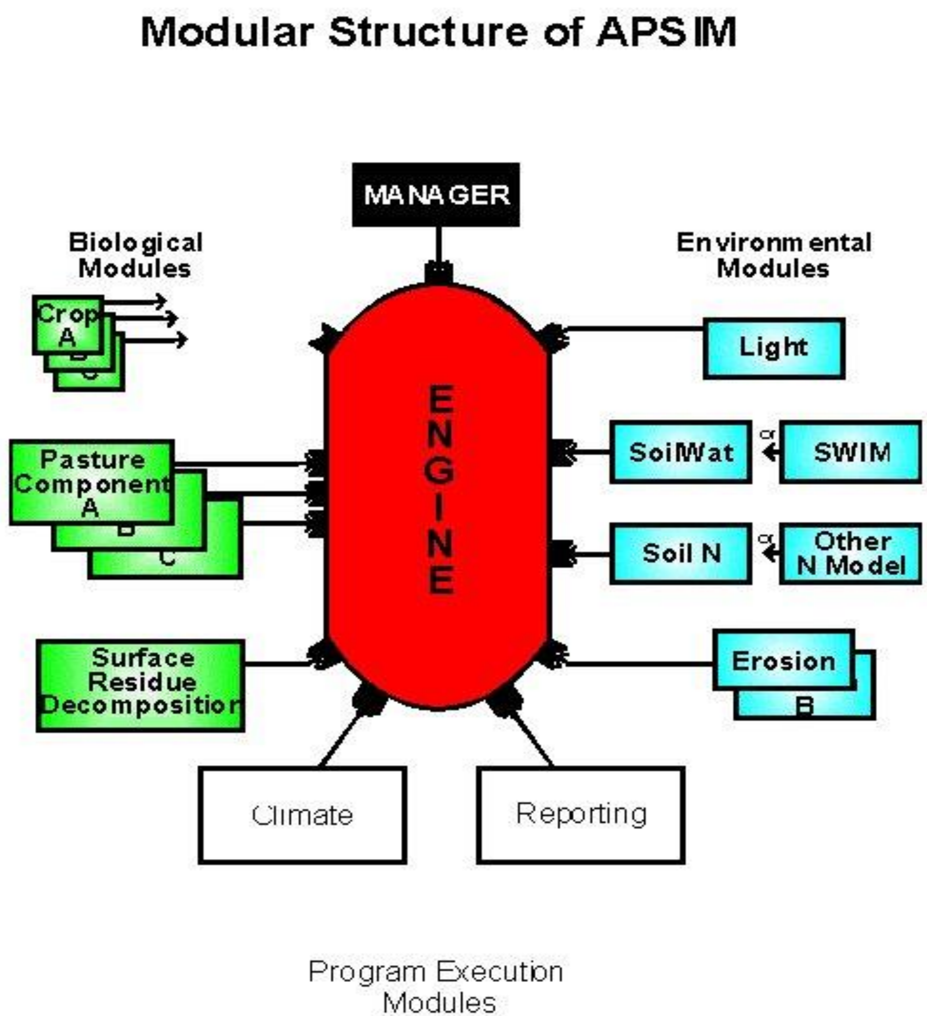
Thanks for you attention!

Contact details:

Prof Roger Stone stone@usq.edu.au
Dr Peter Best peterbest4@bigpond.com
Dr Olena Sosenko ososenko@primacyua.com.au

Weather forecasting and risk management tools: farmer level

APSIM: precise daily time step model that mathematically reproduces the physical processes taking place in a cropping system



Agricultural Risk in Australia

Farmers and others are all ‘swimming in the stormy seas of risk, with and without formal climate forecast’ (Anderson, 2005)

Drought
Flood
Lack of water
Excess of water
Frost
Hail
Bush fires
Wind
Severe storms
Cyclones

Climate risk management through climate indices

- Climate indices are useful for forecasting climate, crop yield and crop price
- Seasonal climate/crop forecasting (SCF) should include evaluation of model errors
- SOI derivatives may attract many wheat market participants (in Eastern Australia).....
- However, development of climate anomaly indices (CAIs) through help of re-analysis data sets may form a base for derivatives and insurance products around the world

Australian farmers are unusual on the world scene

- Exporting the majority of their production but marginally influencing on the world prices
- Operating in an environment of very strong volatility in rainfall, yield and price
- Having considerable exposure to conventional commodity markets

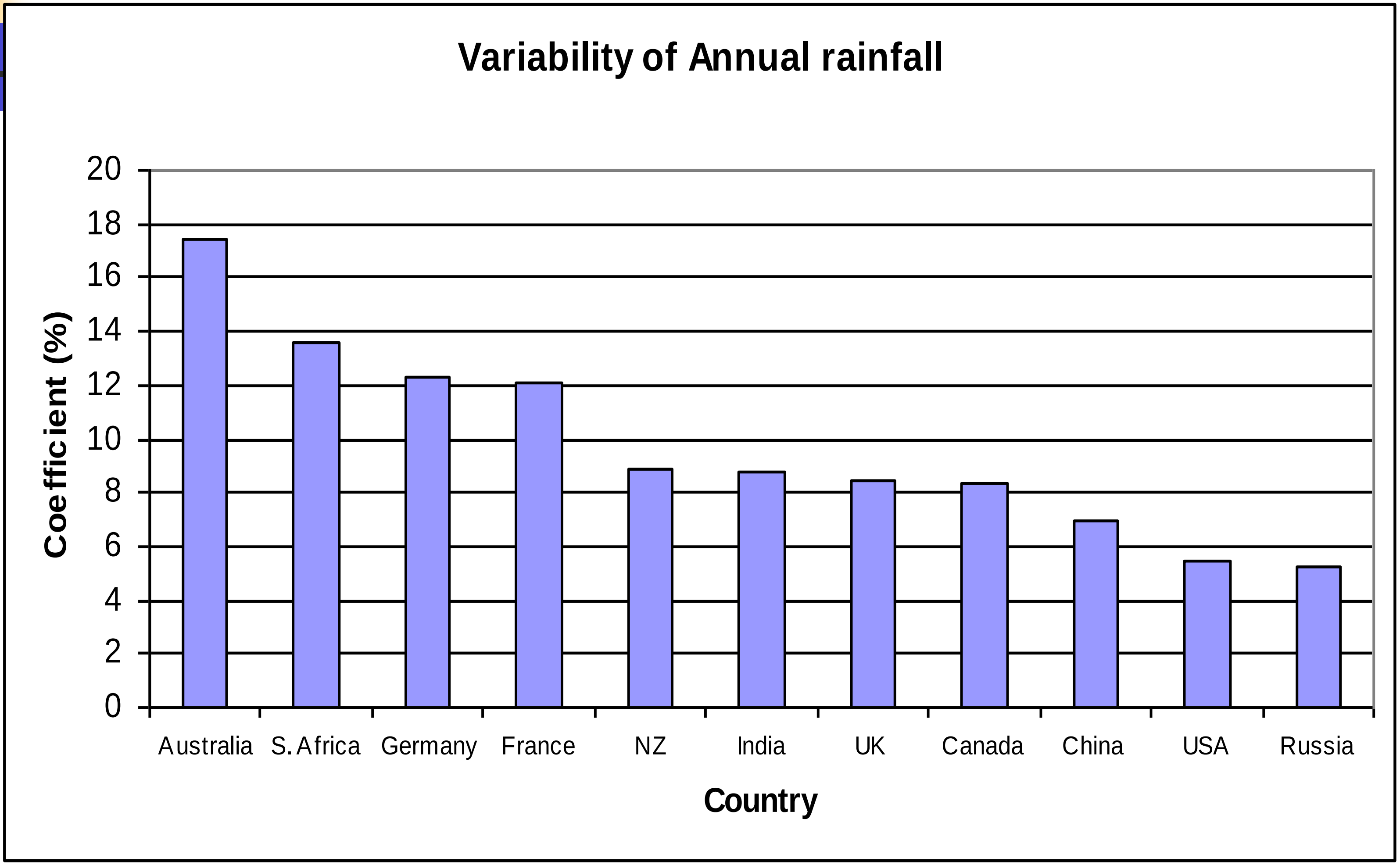
But:

- Having a strong climate adaptation abilities
- To some degree, incorporating seasonal climate forecasting in many forms of decision-making
- Having ready access to government and academic advisors on climate risk management

Weather risk management for Australian wheat to date

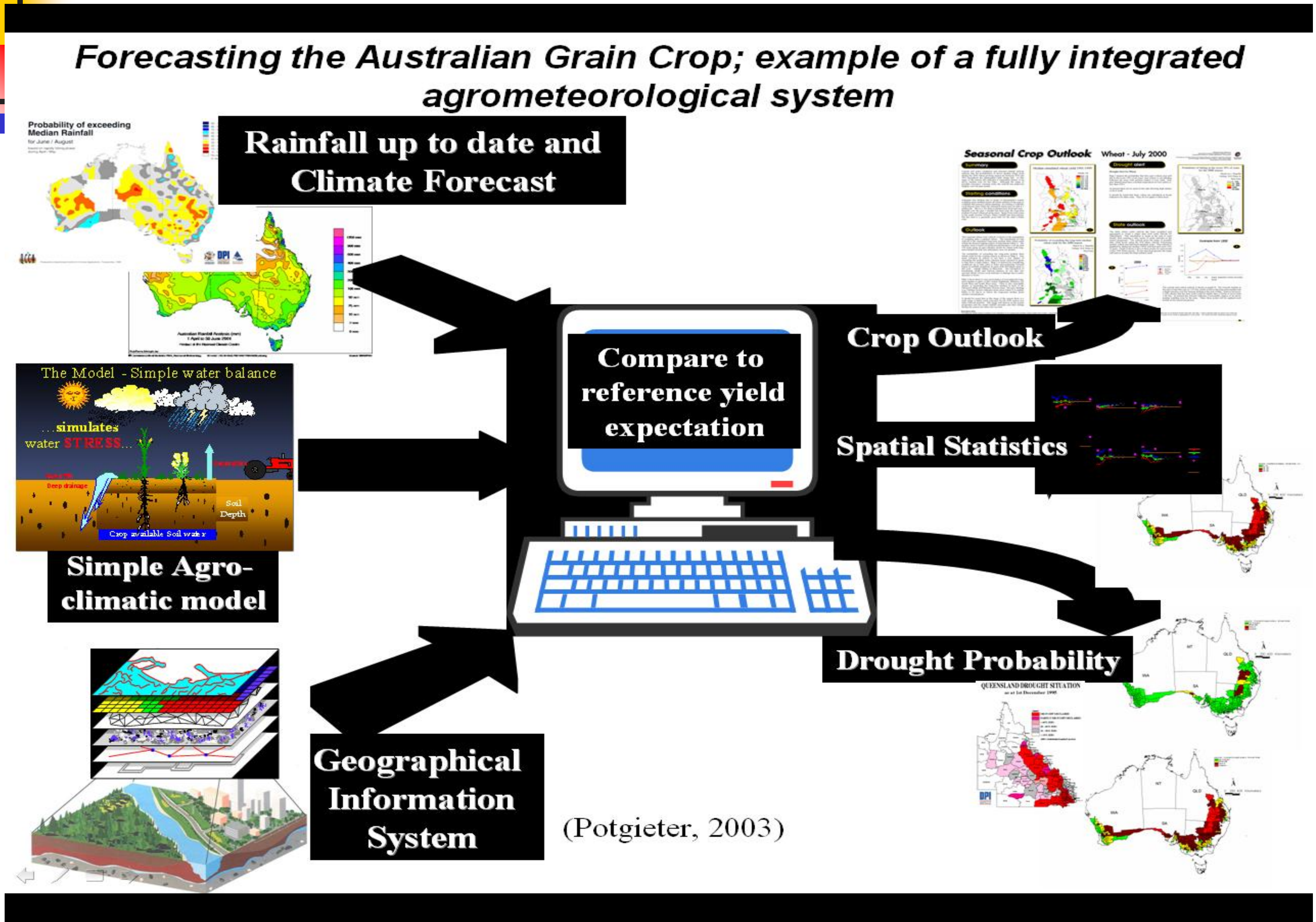
- Hail and fire insurance,
- Use of climate forecasting system for decision-making, especially in NE Australia…
- Trust in SOI-based schemes over past decade of use in some regions..
- ‘Little use of weather derivatives’ (NAB, Sydney Futures)….
- History of large government assistance for drought,
- Interactions with water, energy and bio-fuel market

Rainfall variability



(Love, 2005)

Good example of use of crop simulation models (even this more simple type)…



Agricultural systems, climate systems on many scales and management decisions (Meinke and Stone, 2005)

Decision type (eg. only)	Frequency (year)
Logistics (eg. scheduling of planting / harvest operations)	Interseasonal (>0.2)
Tactical crop management (eg. fertiliser/pesticide use)	Interseasonal (0.2-0.5)
Crop type (eg. wheat or chickpeas)	Seasonal (0.5-1.0)
Crop sequence (eg. long or short fallows)	Interannual (0.5-2.0)
Crop rotation (eg. winter or summer crop)	Annual/biennial (1-2)
Crop industry (eg. grain or cotton, phase farming)	Decadal (~10)
Agricultural industry (eg. crop or pasture)	Interdecadal (10-20)
Landuse (eg. Agriculture or natural system)	Multidecadal (20+)
Landuse and adaptation of current systems	Climate change

a pay-off function of the collar form

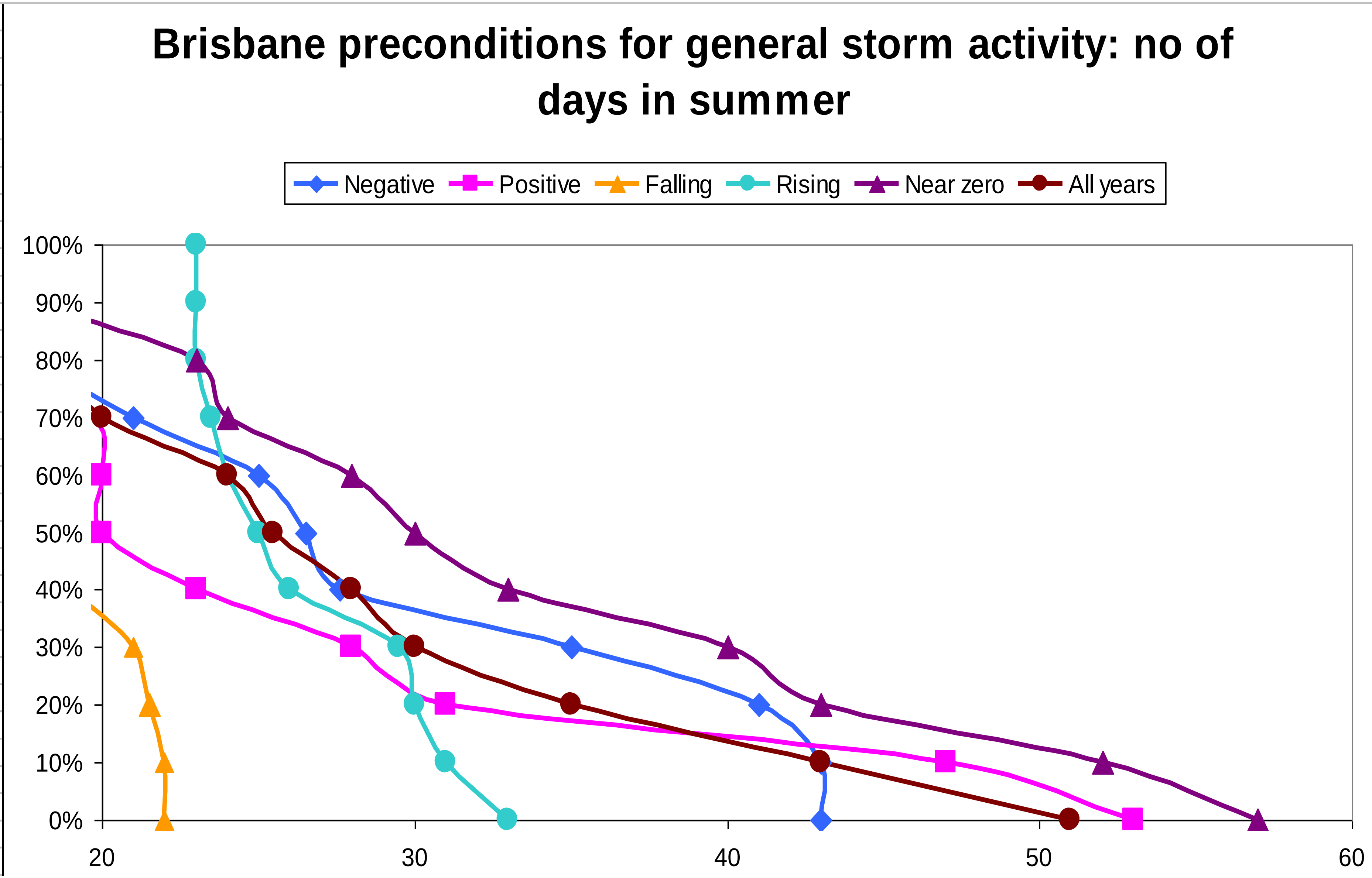
$$F(SOI6) = \begin{cases} m & SOI6 < -12 \\ D1\,(SOI6 + 6) & -12 \le SOI6 < -6 \\ 0 & -6 \le SOI6 < 4 \\ D2\,(SOI6 - 4) & 4 \le SOI6 < 8 \\ -M & SOI6 \ge 8 \end{cases}$$

….where m is the capped payout (6D1) to the farmer for severe drought (characterised by SOI6 below -12) and – M is the capped payment (-4D2) from the farmer in the event of large positive SOI6 (and hopefully a bumper crop). The ratio of D1/D2 may vary between different sites and may well be represented by the site crop yield volatility.

premium to be defined by a transparent pricing process, probably based on the sum of expected pay-off, risk premium and transaction costs;

measurement responsibility in the hands of the World Meteorological Organisation;

settlement agency and methodology possibly to extend over several seasons.



CDFs of severe thunderstorm/hail preconditions in southern Queensland/NNSW – incorporating radiosonde data and SOI ‘phases’.

The NCEP-NCAR daily Reanalysis (Kalnay et al., 1996; Kistler et al., 2001), with a spatial horizontal resolution of $2.5° \times 2.5°$ lat-lon, are used to determine the forcings for hailstorms, partly following the ideas by Brooks et al. (2003); the same forcings are derived from the CGCM2-A2 climate scenario (Flato and Boer, 2001; spatial horizontal resolution of $3.75° \times 3.75°$ lat-lon) provided by the Canadian Centre for Climate modelling and analysis (CCCma), to derive the expected changes of the hailstorm frequencies.

These data are derived from a second generation coupled model (CGCM2) on the basis of the emissions scenarios IPCC SRES "A2" (fast population growth, rather slow economic and technological development, Watson, 2001).

The relevant atmospheric quantities which are potentially associated to the hailstorms frequency and the hail grain size and can be simply computed from both the NCEP-NCAR Reanalysis and the CCCma scenario, are the following (Billet et al., 1997):

- Lapse Rate (LR, difference between the temperature at 850 hpa and at 500 hpa);
- Precipitable Water (PW, water vapor content in the column of atmosphere from 850 hpa to 500 hpa);
- Relative Humidity (RH, ratio between environmental vapor pressure and saturated vapor pressure, averaged at the levels 850 hpa and 500 hpa).